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SOURCE Vizugyi Kozlemenyek, Vol. I, 1951.REGULATION OF THE DABUPE IN HUNGARY

[Figures referred to are appended.]

## I. DESCRIPTION OF RIVER SECTIONS AND REGULATION TECHNIQUES

## A. Classification of River Sections

It is customary, in studies of geography and geomorphology, to differenti-  
 ate between the various sections of a river according to the way they respond to  
 the resistance exerted by the walls of their channels.

In a river section where the power of the current exceeds the cohesive power  
 of the channel wall, the water erodes the wall, deepening the river bed and carry-  
 ing the eroded material downstream as sediment. In Cholnoky's terminology, this  
 is an "upper-river" type section.

When the current is too weak to attack the channel walls or even to carry  
 its load of sediment downstream, part of the sediment is deposited. Then the  
 bottom rises, sand bars and islands are formed, and the channel branches off.  
 Cholnoky has named such sections "lower-river" types.

Finally, where the current has just enough power to carry the sediment  
 along, the river bed remains in a state of equilibrium. Cholnoky's names this  
 a "middle-river" type section.

However, Cholnoky's classification does not correspond to the actual  
 hydraulic characteristic of rivers. The rate of fall of a river generally di-  
 minishes gradually from its source to its outlet. Natural and artificial ob-  
 stacles (configuration of mountains, reservoirs, etc.) may interrupt or even  
 decrease but do not change the over-all gradual diminution of the fall of a  
 river along its successive sections. In places where the fall is most gradual,  
 the speed and strength of the current diminish most, and sediment is deposited.

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Such places are always encountered when the river leaves a mountainous section before entering a level section. Cholnoky's terminology is therefore misleading. The type of section corresponding to his "lower-river" type is actually found directly below the upper or mountainous portion of a river, and its downstream continuation corresponds to the type of section which Cholnoky describes as the "middle-river" type.

For the purposes of river-regulation work the true characteristics of a river are more accurately designated by the following terminology: rapidly descending, or mountainous, section (Cholnoky's upper-river type); depositing section (Cholnoky's lower-river type); and level section (Cholnoky's middle-river type). This sequence gives a true picture.

#### B. Characteristics and Administration of the Hungarian Section of the Danube

The section of the Danube extending from Deveny [Czechoslovakia] to Gonyu (1,791 kilometers) is of the depositing type. Its continuation below Gonyu along the Little Hungarian Plain, as well as the section which borders the Great Hungarian Plain to the west and south between Kismaros and Bazias (1,688-1,075 kilometers), is of the level type. Between these two level-type sections a mountainous section extends from the mouth of the Garam River to Kismaros (1,715-1,688 kilometers). However, since the original breakthrough of mountainous territory is now complete, the slope has become gentle and the flow is of a level type.

Therefore, along the 416 kilometers of the Hungarian section of the Danube, we can distinguish (1) the depositing section, which extends to the mouth of the Moson branch at Gonyu (1,850-1,791 kilometers), and (2) the level section below it, which, in turn, can be divided into two sections according to the quality of its sediment content. Approximately as far downstream as Paks (1,791-1,533 kilometers), the stream rolls part of its sediment on the bottom of the river bed. Below Paks (1,533-1,434 kilometers) the sediment is carried in suspension. Small pebbles might still be found in this section, but the character of the river changes below Paks and meanders are formed.

The Hungarian section of the Danube extends from the Czechoslovak border to the Yugoslav border (1,850-1,434 kilometers). The section above the confluence of the Ipoly and the Danube forms the frontier between Hungary and Czechoslovakia.

The Gyor River Regulation Service is responsible for the maintenance and regulation of the section dividing Hungary from Czechoslovakia (1,850-1,708 kilometers); the Budapest River Regulation Service is responsible for the section extending from the mouth of the Ipoly River to Dunafoldvar (1,708-1,560 kilometers); and the Baja River Regulation Service is responsible for the section between the Dunafoldvar Bridge and the Yugoslav frontier.

#### C. Methods of River Regulation

In general, it is customary to differentiate between three problems in river regulation namely, floodwater regulation, average, or normal, water regulation, and low-water regulation.

In Hungary, the purpose of floodwater regulation has been to protect from inundation the valuable land along the river banks which was or could be brought under cultivation. In the past, the advantages of flood protection were enjoyed primarily by the landowners whose territories were protected by these measures, and they were entrusted with building flood-control works. It is only natural that the landlords concerned themselves only with the problem of flood control and disregarded the effect these works might have on the river bed. As a result, the system of flood-control dikes along the banks of the Danube in Hungary still leaves much to be desired.

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Average water regulation concerns itself with the entire normal channel between the permanent banks. The purpose is to insure an even flow of water, ice, and sediment; in other words, to prevent accumulation of water or excessive drainage and the formation of ice barriers, washouts, and rises or drops in the river bed. If a state of equilibrium in the normal channel is maintained, the required width and depth of the navigation channel is also insured. Low-water control is a supplementary measure to insure better navigation.

If the river tends to broaden its channel, with a resulting decrease in depth, greater depth must be insured by narrowing the channel to provide for unobstructed navigation. First it is necessary to determine the average profile required to conduct the low-water volume. The horizontal diameter of this profile represents the desired width of the improved channel.

Narrowing of the channel can be accomplished through the use of longitudinal dikes or transverse spur dikes. The first method insures a more even flow and is usually less expensive. But if it is not adequate, the position of the whole length of the longitudinal dikes must be changed and regulation started over again. For this reason, regulation by the use of spur dikes is preferable. If the resulting width should prove too great, elongation of the spurs is relatively easy, and if the regulated channel proves too narrow, the ends of the spurs can be shortened with grapple dredges. The disadvantages of spurs are that they require more construction material than longitudinal dikes because the spurs must be supported at the banks, and they result in a less even flow of water.

Schlichting tried to eliminate the disadvantages by combining the two methods of regulation. On the concave side of a bend he built only longitudinal dikes which conduct the water easily, and on the convex side he used only spurs which narrowed the channel. Then, if the desired results were not obtained, the length of the spurs could be changed.

The French river engineers Fargue and Girardon showed that, under natural conditions, rivers flow in a succession of alternate bends and that their profile varies at each point along these bends. At the apex of the bend, the profile is narrowest and deepest and at the transition or inflection points it is widest and shallowest. Girardon regulated the Rhone River by using the system of changing average profiles. His method is applicable to both average and low-water regulation.

#### D. Regulation of the Hungarian Section of the Danube

Longitudinal dikes are the most suitable method of regulation for the depositing-type section of the upper Danube in Hungary and can be supplemented by regulation of the low-water channel. However, the latter method was not known at the time regulation of the middle section of the Danube was begun.

Regulation of the Vas Danube branch, the average channel of which had not previously been made permanent, was begun with modern methods in 1949. Application of these methods could have been extended as far south as Paks, that is, along a section in which deposits are still being carried on the bottom of the Danube.

Below Paks, where the Danube carries its sediment mostly in suspension, and the bottom and sides consist of fine material with little power of resistance, spur dikes could not protect the banks against erosion or prevent the river from forming bends or from shifting its channel. Along this section the concave banks must first be stabilized and protected as a preliminary step to the development of a uniform, well-formed channel, which is important not only for shipping but also for the prevention of spring floods.

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A general plan for the improvement of the upper Danube was prepared in 1936. This followed plans for the regulation of the normal channel in 1880 - 1882, and of the low-water channel in 1899. A general plan for the improvement of the middle Danube was prepared in 1893 and of the section between Budapest and Paks in 1942. As mentioned above, the general plan for the improvement of the Vac branch was prepared in 1949.

A plan for the improvement of the section between Paks and the Yugoslav frontier still has to be prepared. This section has special problems, particularly in connection with ice floes.

A uniform low-water level for the whole Hungarian section of the Danube must insure the minimum level necessary for navigation.

In regulating the upper Danube, the minimum low-water level used for guidance was the so-called CID (Commission Internationale du Danube) level. This was established after World War I by the International Danube Commission on the basis of data obtained during the shipping seasons (1 March to 25 December) of the years 1902 through 1921, but not taking into consideration the ten lowest recorded water levels.

On the Hungarian section of the Danube below the Ipoly River, the so-called basic water level of 1930 was used for regulation purposes. This basic water level is lower than the CID water level by approximately 50 centimeters in the section above Budapest, and by 50-70 centimeters in the section below Budapest.

Since in the sections above and below the mouth of the Ipoly River the regulating services were guided by different water levels in their improvement works, the Hydrographic Institute in 1943 proposed a new uniform low-water level based on the levels of 3,400 out of the 3,652 days of the previous 10 years. For the period 1931 - 1940 it differed by only a few centimeters from the CID water level. The CID has the responsibility of introducing a uniform shipping level, or rather regulated low-water level, for the whole Danube River.

It is also necessary to arrive at a uniform width for regulation. Along the upper Danube, from Deveny to Dunaradvany (1,880-1,747 kilometers), the width was already determined in connection with the regulation of the normal channel. The regulation width for the section below Dunaradvany to the mouth of the Tisza River (1,747-1,212 kilometers) was determined at 450 meters in 1893. In 1941, the Technical Subcommission considered a width of 400 meters sufficient for the section between Budapest and Paks (1,647-1,533 kilometers). This width can be used for the whole section extending from Dunaradvany to the Yugoslav frontier. An exception is the Vac branch, between Kisarozsi and Budapest, where the regulation width of the main channel is 380 meters.

The question of depth in the upper Danube was the subject of an international agreement. The goal was to insure adequate depth for vessels with a 2-meter draft. It was possible, however, without any particular difficulty, to insure a depth of 3 meters along the sections below Gonyu. The River Regulation Service, in its general plan for the Vac branch in 1949, determined the depth of the shipping channel, for a width of 180 meters, at 2.75 meters below the CID water level and 2.25 meters below the basic water level. For a channel width of 160 meters, the depth was determined at 3.00 meters below the CID level and 2.50 meters below the basic level. The general plan prepared by the River Regulation Service is intended to insure an adequate depth below the basic depth for ships with a 3.5-meter draft.

The National Water Economy Council determined that improvement works for the Hungarian section of the Danube River must insure the following depths below the minimum shipping depth (CID water level), as determined by the International Danube Commission: for the frontier section above Gonyu, 2.5 meters; for the section between Gonyu and Budapest, 3.0 meters; for the section below Budapest, 3.5 meters.

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It will take a long time before the shoals of the Lower Danube and of the Yugoslav section of the Danube can be improved to a depth of 3.5 meters and made navigable for seagoing craft. Once work in these sections is begun, however, the project can be started concurrently to make the Hungarian section below Budapest navigable. A depth of 3.5 meters below the CTD water level will offer adequate protection against floods by melting ice.

#### B. Sediment Content of Rivers

The sediment of rivers is the solid material which the water carries along with it. In the regions of the headwaters, huge boulders roll down into the valleys. These are brought into motion by the water during heavy floods. Then the water which has seeped into the cracks of the boulders freezes and widens the cracks. Meanwhile, the pounding wears away the stone surface and makes it smooth. The stones break up into small pieces which end up in the permanent water channel, where their movement becomes continuous and is no longer restricted to times of flood. Their size decreases constantly and eventually they are broken into such small grains that the pressure of the stream on the surface of the particle exceeds the particle's weight. The sediment no longer stays at the bottom, but is carried along suspended in the water.

Sediment carried on the bottom of a river bed is composed of a more or less even mixture of particles of all sizes. In the Danube, the sizes of the largest sediment particles range from the size of a child's head at Deveny, to first size at Rajka, egg size at Gonyu and nut size at Esztergom. The tributaries, particularly the Garam River, again coarsen the detritus and bring first-sized pieces into the Danube; however, from here on, the sediment particles are again continuously ground up.

In general, the largest pebbles found in the Vac branch are the size of a nut. In their progress downstream their size decreases constantly and at Uszod only pea-sized pebbles remain. Further along, even the sediment which is carried on the bottom consists only for sand, which becomes so fine at Mohacs that it is difficult to find particles measuring one millimeter in diameter. In the section below Uszod, sediment is carried largely in suspension.

## II. THE UPPER DANUBE

### A. General Characteristics

The section above Deveny is of the mountainous type. Its geographic name is Upper Danube. The section extending from Deveny to Gonyu (1,880-1,791 kilometers) is actually a transition between the mountainous and level types. Here the rapid flow of the river changes to a slow descent. The river is not moving over a plain yet, but moves over its own alluvial cone of sediment deposit which spreads over its raised channel bed. The designation of Upper Danube also covers this transitional section of the river. Its slope is still quite pronounced (35-40 centimeters per kilometer); however, since it spreads out and its depth is slight, it cannot carry all of its detritus along, but deposits the coarsest grains. There is a resulting rise in the channel bed and in the height of the water level. This rise is accompanied by a rise in the subsoil water level of the surrounding regions.

In sections where sediment is deposited, sand bars emerge under natural conditions and are gradually built up into islands. The channel branches off, forming numerous forks and islands. No definite main channel develops among the many branches and every change of current may bring about sudden shifts in the

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channels; one channel may fill up and another may deepen. This unstable state is unsuitable for the discharge of ice floes downstream and also for shipping, and threatens the surrounding countryside with inundation.

However, a branching river section has the advantage of serving as an equalizing channel. Part of the water volume is held in storage, filling the side channels and the gaps in the crude gravel layer which covers the sediment cone. The current leaves the section with a decreased volume of water, acts as a check on the water level in the section below, moderates the volume of flow, and plays a particularly important part in protecting Budapest against floods.

While the drop along the mountainous section above is approximately 35-40 centimeters per kilometer, it gradually decreases throughout this section and becomes only 8-10 centimeters per kilometer in the following level section. The water level falls quite suddenly at Szap (1,810 kilometers), which lies at the lower edge of the alluvial cone. Here the rate of drop decreases, within a section of only 2-3 kilometers, from 35 centimeters per kilometer to 15 centimeters per kilometer.

Before improvement was started, the channel of this section of the upper Danube was in a state of deterioration. The river wore away its banks and destroyed valuable areas. Ice floes along the numerous branches were easily arrested by sand bars and islands and the ice formed blocks sometimes as far back as the Austrian section of the Danube, resulting in destructive spring floods. This section was also unsuitable for shipping. The temporary forks did not furnish a channel of sufficient depth and width to allow for the passage of ships. Even an inadequate shipping channel could be found and marked only with great difficulty.

#### B. Regulation of the Average Water Flow

The transitional or upper section of the Danube was regulated in 1886 - 1896 mainly for the purpose of improving the conditions of navigation, but also to prevent the formation of ice barriers. This regulation resulted in the control of the average water flow. Between Neveny and Bos (1,880-1,820 kilometers) the normal channel was narrowed to a width of 300 meters by longitudinal dikes. Below Bos to Vezek, the width became 380 meters and from then on to Dunaradvany, 420 meters.

The axis of the average channel was plotted in such a way as to avoid disturbing the continuity of bends either by sharp curves or by long stretches. Longitudinal dikes were placed where the line of regulation ended in the channel; where it ended on an island, the island was cut through. In the latter case, a rock lining was built along the newly-formed bank of the island.

To protect the banks (see Figure 1), these were cut to a slope of 1.5/1, and a base of rocks was built to a height of 2 meters above zero water level (which corresponds to +4 meters since the lowering of the zero point of the Bratislava water gauge). This base of rocks was 2 meters wide at the crest and had a slope of 1.5/1. The reinforcement itself rests on this rock base and consists of a 15-centimeter-deep layer of rubble or gravel covering the cut bank and, in turn, is covered by a 25-30 or perhaps 40-centimeter-thick layer of quarry stones. The rock base was not covered, since it might give in in the event of erosion and the stone might have to be replaced. But in places where the bank was subject to particularly strong pressure, it was reinforced with a layer of stone, which was extended one meter horizontally toward the bank. The line of regulation fell on the middle of the crest of the 2-meter-wide rock base.

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The longitudinal dikes (see Figure 2) have a width at the crest of 2 meters, with covering shell 25 centimeters thick. The height of their crest above the former zero gauge-level (before the gauges were lowered) is 3 meters in the section above Bos and 2.75 meters below Bos. Their slope on the water side is 1.5/1 and on the shore side 2/1-1.5/1. Occasionally there are 2-meter-wide buttresses on the channel side at the level of the low-water stage. The longitudinal dikes were made permanent by 30-centimeter-thick covers prepared without mortar.

The cuts (see Figure 3) were dug out in widths of 80-100 meters. Material above the water level was removed by manual labor, and below the water, down to a depth of 2 meters, by dredges. In other words, only about one third to one-fourth of the whole depth of the required cross section was dug out. The rest was, as was customary at that time, left to the sweep of the current admitted into the guiding channel. At the cuts, one-meter-high blocks of quarry stone were placed along the line of regulation (see Figure 4). The width of these blocks varied with the height of the area. After the water had cut through and washed away the bank up to the line of regulation where the stone blocks were, the latter caved in and the stone slid into the water. The amount of stone in the block was sufficient to line the channel down to its bed and to protect the new bank against further erosion.

Subsidiary channels had to be dammed off to prevent the escape of average- and low-water volumes, which would lower the water level of the main channel. The dams (see Figure 5) were built either at the openings of side branches -- in which case they were of the longitudinal type, located along the line of regulation -- or some distance down the side channels as transverse dams closing the channel beyond them (see Figure 6). These transverse dams were connected with the longitudinal dikes on the bank. The dams were built similar to the longitudinal dikes but usually somewhat stronger. Their protected side was reinforced 2 meters below their crest with buttresses 2-8 meters wide. These dams were covered with stone above the low-water level.

Side-channel dams were placed usually in channels which were relatively even and had strong banks. It was believed better to build the dams in a deeper channel, even if this involved more material and work, than on a sand bar. Water which overflows the dam or seeps through under it erodes the channel bed and undermines the barrier; therefore, a low dam is easily demolished.

Transverse dams in side channels were built only to a height corresponding to or slightly above low-water level, because their only purpose was to keep the low-water volumes in the main basin. They are usually 2 meters wide at the crest. Their height and width is greater only when they also serve for vehicle traffic. The water which overflows such dams has a considerable scouring effect and whirlpools are formed along their juncture with the banks which, in turn, scour the channel bed and erode the banks. Protection against scouring is obtained by covering the channel bed on the far side of the barricade and by building strong reinforcements along the banks. The bed is protected by a layer of stones or of brushwood. The shore reinforcement extends 20 meters above the dam and at least 50 meters, or a length representing one fourth of the channel width, below the dam. Construction material used in transverse dams is either quarry stone or fascine covered with a 0.5-1 meter thick layer of quarry stone or with concrete.

#### C. Results of Regulation of the Average Channel

The regulation of the average channel of the upper Danube has resulted in a marked improvement in the discharge of water and ice as well as in greater navigability. Ice barricades now develop rarely and cause less damage. Ships now have a channel in which it is easy to find the course of greatest depth. Sudden curves have disappeared and shoals are more easily avoided.

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However, regulation of the average channel has also had unfavorable results. The bottom of the upper part of the improved section became deeper, while sediment was deposited along its lower part, causing a rise in the channel bed as well as in the water level. Bars of gravel were deposited along the channel (at Kisbodak, Szap, and Medve, 1,827-1,805 kilometers) and were surrounded by shoals. In some of these shoals the water was only 110-115 centimeters deep.

The 300-380-420-meter width proved to be too great. Longitudinal dikes could not sufficiently contain the water volume at low-water levels, with the result that this volume spread throughout the normal channel and no longer maintained the required depth within the line of current. Hopes for the beneficial effect of the so-called gates, which were gaps left purposely in the longitudinal dikes, were not realized. It was thought that these gates would allow the water flowing through them into the side channels to deposit sediment and thus hasten the process of filling up the side channels, deepening the main channel, and improving its discharge capacity.

But the effect of the gates is just the opposite. When the water level in the main channel is above normal, sediment is carried into the side channels over the top of the longitudinal dikes and only an insignificant proportion of this sediment reaches the side channels through the gates. On the other hand, when the water level in the main channel is below normal, water flowing through the gates is not likely to carry any sediment. This diversion of the water volume weakens the power of the current in the main channel so that it is not able to carry downstream the sediment which has been deposited in the form of sand bars near the gates as the water subsided. The problem of the use and placement of the gates is still under discussion. The Hydraulic Service would like to solve this problem by experimentation on small scale models.

#### D. Low-Water Regulation

For the reasons outlined above, it was necessary to begin low-water regulation as early as the beginning of the century, to supplement the regulation of the average water volume. The control of low-water levels definitely serves the interests of shipping. Toward this end, the goal for the time being is to create, at low-water levels, a depth of 2 meters and a 100- to 150-meter-wide shipping channel. It is also intended to avoid sudden changes of depth at shoals and to insure a gradual transition in depth at such places. Regulation of the low-water volume means concentration of this volume within the normal channel and the contraction of the normal channel for the purpose of insuring the required depth. Therefore, it involves additional closing of side channels and narrowing of the main channel.

An attempt was made to establish identical profiles for all points along any given section of the river. Because results were not entirely satisfactory, Girardon's method was tried for creating the required navigation depth. Low-water regulation if applied consistently, should in time (8-10 years) insure a depth of 2.5 meters below the minimum navigable water level.

The first step is to plot the line of current correctly. Long straight stretches must be avoided, but otherwise it is necessary to adhere to existing regulation works (see Figure 7). The topographic diagram of the direction of the current shows a succession of alternate curves. Observations along the upper Danube have shown that half wave lengths of the bends, measured between inflection points, generally vary between 1,100 and 1,300 meters. At the apex of the bend, the line of current is usually found at a distance of 50-80 meters (one fourth to one fifth of the width of the channel) from the longitudinal dike on the concave side. At the inflection point, the line of current falls in the center of the channel.

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## 2. Methods of Low-Water Regulation

Regulation constructions can be either longitudinal or transverse. The former consist of longitudinal dikes or embankments and side-channel dams. The second type consists of transverse or spur dikes and bottom locks. Along the upper Danube longitudinal dikes already exist for regulation of the average channel, while additional dikes for low-water control are built only exceptionally. Instead, changes are made in the existing works by correcting them, increasing their height, strengthening them, making them permanent by cementing, or by closing off the gates left in them.

Continuous longitudinal dikes of uniform height, which were built for regulation of the average channel, often have the effect of attracting the current line toward them more strongly than necessary.

The primary purpose of spur dikes is to narrow the channel, but they also direct the flow of water. In regulating the channel along bends, longitudinal dikes are used on the concave side and spur dikes on the convex side. Besides narrowing the channel and directing the water flow, spur dikes are also useful in promoting silting along the convex side.

For the improvement of a deteriorated section of several kilometers, spur dikes are distributed along the planned line of current. The required distance between spurs varies because of changing hydraulic conditions (water level, slope, depth, width, velocity, power of the current, sediment content, etc.) For the Danube River, it has proved satisfactory to make this distance half the width desired in the regulated channel. The 300-meter-wide regulated channel of the upper Danube requires spurs distributed at distances of 150 meters.

The first spur of the series is placed at the inflection point of the bend. Spurs are not perpendicular to the shore or to the current line, but are directed upstream from the shore in order to conduct the water toward the current line. They form an angle of 15 degrees with a line drawn perpendicular to the current. This distribution of spurs as a frame to the development of the kind of channel to be achieved by regulation. The ideal channel profile at the inflection point is a parabola with a width at the CID level equal to the width mentioned above (300 meters above Bos and 38-420 meters between Bos and Gonyu) and a depth 3 meters below the CID water level (see Figure 8).

The profile at the apex of the bend differs from that at the inflection point only in that it is not symmetrical but an asymmetrical parabola, whose axis lies at a distance of 50-80 meters (one fourth to one fifth of the channel width) from the concave side, but whose depth, measured at the current line, is still 3 meters greater than the CID level (see Figure 9). The crest of the spurs along the line of regulation is 75 centimeters below the minimum navigation water level both at the inflection point and at the apex. Below their crest, the spurs are directed tangentially to the curve of the parabola. As a result, the slope of their crest is steepest in the inflection point profile and least steep in the apex profile. Transition between the two is gradual.

It is not customary to construct every single component spur of a planned series. To conserve construction materials, only two or three of any given series are actually built, usually numbers one, three, and five, or two, four, and six. The others are built only if they are subsequently found to be necessary. The spurs have the following dimensions: width at the crest, 2 meters; upstream slope, 1/1; downstream slope, 3/1. Construction material is quarry stone (see Figure 10).

Dredging is used in places where the channel-deepening effect of spur dikes needs to be speeded up. By this means the required depth and width of the shipping channel can be obtained within a matter of weeks, or even days. Dredging is never as an independent method because its effect is not lasting. The

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sediment content of one or two flood waves will quickly fill up the dredged channel. For this reason, when possible, dredging is used only in conjunction with the building of spurs. The function of the spurs then is to conduct the water into the dredged guide channel, where its scouring effect will prevent filling up the channel.

#### F. Low-Water Regulation Construction

Emil Schick of the former River Engineering Department of Bratislava began regulation of the low-water channel of the Danube at the beginning of this century according to the methods outlined above. He started with the section Kortvelyes and Vajka (1,842-1,835 kilometers), then proceeded to the vicinity of Bratislava, and finally to the section between Csaszarliget and Kisbodak (1,840-1,829 kilometers). The outbreak of the World War I handicapped the construction work and in 1916 it had to be stopped entirely for lack of labor, material, and money.

Construction was practically unnecessary along the section between Orosvár and Kortvelyes (1,855-1,842 kilometers). In the section between Kortvelyes and Suly (1,842-1,832 kilometers), the shipping channel was improved considerably, but deteriorated again when work was stopped because of the war. Where spurs had already been built and contracted the channel, sediment was not deposited and was carried further down. But because the necessary construction could not be completed in the section below, sediment was deposited here and filled up the channel.

After the World War I, the section of the Danube between Horvátjarfalu and the mouth of the Ipoly River (1,862-1,708 kilometers) became the frontier between Hungary and Czechoslovakia. During the first postwar years, the construction underwent grave deterioration. The longitudinal dikes were breached by ice so that water escaped into the side branches even when the water level was low. The volume of water remaining in the shipping channel was insufficient. Sediment was deposited so that the channel deteriorated at many places.

Only in 1927 was reconstruction work of any significance on the longitudinal dikes and shore reinforcements begun. The work was carried out under the direction of a joint technical commission formed for this purpose by agreement of the two countries. But improvement could not be continued where it had been left off during the war. Instead, it was necessary to concentrate on those places where deterioration presented the greatest obstacles to navigation. Low-water regulation continued with the building of new dams to close off the side channels and with the improvement of shoals along the main channel, always as dictated by immediate necessity. Improvement of shoals was made by building spur dikes and by dredging.

After several years of work, it was discovered that the quantity of detritus deposited between Kisbodak, Szap, and Madva (1,827-1,805 kilometers) had resulted in raising the channel bed. Regulation works built according to the old methods could no longer function. To contract the channel more effectively, the longitudinal dikes, whose relative height had diminished due to the rise of the channel bed and the water level, had to be raised, to correspond to the new water level. Spur dikes had to be built according to new and more effective methods.

#### G. Modification of Low-Water Constructions

Spur dikes built according to the old methods were not found to be sufficiently effective. They are low, their surface is small, and they cannot constrict the profile of the channel adequately. The Hungarian River Regulation Service tried

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to make the spurs more effective by changing their location and dimensions. Since the channel had already proved too wide for satisfactory average-flow regulation, Hungary proposed that the excessive width be narrowed by 100 meters at the apex of the bend and by at least 10 percent (15 meters from each bank) at the inflection point. The line drawn through these two points is called the line of constriction.

Distribution of the spur dikes according to the new, modified system is also along the line of current (see Figure 11). The first spur of the series is at the inflection point. The rest follow downriver at approximate distances of half the width of the channel. The ends of the spurs form an angle of 15 degrees to the perpendicular of the line of current in the direction of the flow. The portion of the spur dikes which lies between line of regulation (the shore and the longitudinal dikes) and the line of constriction is high and resembles a dam and its crest is level and gently sloping (1-2 percent at most). The portion which extends from the line of constriction into the channel, the actual spur itself, has a much steeper slope.

The height of the spurs is determined at the line of constriction. The height of the base of the spur which lies in the inflection point profile is the same as in the original system -- 75 centimeters below the minimum navigation level. The spur located in the apex profile, where the constriction is greatest, has the height of its base 100 centimeters above the minimum navigation level. The height of the base of the spurs, therefore, rises along the line of constriction from the inflection point to the apex. This gradual rise is not linear but follows a sine curve.

It has been observed that depths measured along the line of current are smallest at the inflection point and greatest at the apex of bends. At the inflection point, the depth below the minimum navigation level often measures hardly one meter, while the depth at the apex generally varies between 4 and 6 meters. With this in mind, the Gyor River Regulation Service ruled that the depth along the line of current must be 3 meters at the inflection point and 6 meters at the apex. Transition between the two is gradual (see Figure 12-14).

Spurs constructed according to the above system made regulation considerably more effective because their channel-constricting capacity is greater. At the same time, they are better suited to the natural configuration of the channel, because the slope of the crest of the spurs is most gradual at the inflection point and steepest at the apex and their base is lowest at the inflection point and highest at the apex. In comparison with the old types, the surface of these spurs is much greater and takes up a considerable section of the profile of the deteriorated channel. Spurs have been constructed according to this method since 1936 and the innovation has proved effective in the improvement of several shoals.

#### H. Construction Materials

Longitudinal and spur dikes are built out of quarry stone. (This stone is obtained by the Czechoslovak River Regulation Service from the Deveny quarries and by the Hungarian Service of Gyor from trans-Danubian quarries along the river.)

More recently, a substitute stone has proved very satisfactory and is more easily transported to the construction site in blocks of 20-30 kilograms. The new material is made by mixing 100 kilograms of gravel found on sand bars, or dredged from the river bed, with one cubic meter of cement.

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Brushwood cylinders filled with gravel have been used in building dams and shore reinforcements in the forks of the upper Danube. Brushwood can usually be grown in sufficient quantities near the construction site and gravel can be found in the side channels. The diameter of the brushwood cylinders is 0.8-1.8 meter and their length 8-10 meters, sometimes longer. Whether used as the framework of side-channel dams or as foundation piles, the brushwood cylinders are covered with a 0.8-1.0-meter-thick layer of quarry stone or cement in order to increase their resistance to the action of ice and water.

### III. THE MIDDLE DANUBE

The depositing section of the upper Danube is followed by a level section below Gonyu. The river carries much sediment above Gonyu and, as the power of the current diminishes, a part of the sediment settles. Below Gonyu the river is able to carry its sediment, although, as far as Paks (1,791-1,533 kilometers), some of it is still rolled along the river bed. Below Paks, most of the sediment is carried along in suspension.

For purposes of this discussion, it is useful to divide this section into parts according to whether sediment is dragged along the bottom or carried in suspension in the water.

#### A. The Section With Bottom-Rolled Sediment

Where sediment is dragged along the bottom, the possibility of its accumulation still persists. During floods, more sediment is carried than at average- or low-water levels. With the subsequent decrease in water volume, part of the sediment must be deposited. As a result, sand bars exist even below Gonyu. The movement of detritus must have been particularly great at the time of the development of the Danube channel before the breakthrough of the Szob-Visegrad section was completed. The river carried part of the alluvial deposit of the Little Plain and laid it down along the section below Visegrad, forming the islands which dot the Danube between Kismaros and Paks (1,693-1,533 kilometers).

The islands of the section between Gonyu and Esztergom (1,794-1,718 kilometers) are undoubtedly the lower extension of the island system of the upper Danube. Before there was any flood protection, flood waters spread freely over this section and sediment was deposited throughout the inundated area. The average channel is too wide in several places and average- and flood-water volumes are dispersed, depositing some of their sediment content and forming sand bars, islands, and shoals in the navigation channel.

At the mouth of the Garam River, the disadvantages of this wide channel are increased, because the Garam River has a big sediment content, most of which is deposited at its mouth. Consequently, the confluence of the Garam and the Danube abounds in sand bars which, sooner or later, are covered with vegetation and develop into islands. Such are the islands of Helemba, Deda, and others.

The mountainous section between Domos and Visegrad (1,699-1,693 kilometers) can now be said to have "matured," for its profile is sufficiently deep and wide and its slope fits into the slopes of the level section above and below it. However, the rocks which protrude out of the channel at low-water levels are a menace to navigation. The River Regulation Service has mapped and measured these rocks and marked them in the shipping channel so that ships can avoid them, but they must be removed eventually.

At the time of its breakthrough in the Visegrad section, the Danube deposited an alluvial cone at its entry into the Great Plain. The remains of this deposit are still seen in the islands between Visegrad and Gerjen (1,693-1,516 kilometers) which divide the main channel into branches.

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The extended channel of the Danube at these places is too wide. The water spreads out and deposits part of its sediment content. Low-water volumes are inadequate for removing this accretion from the excessively wide channel bed. The smaller side forks need to be closed off and the average channel should be narrowed by use of spur dikes. Actually the side forks have already been dammed off by the former Hungarian River Engineering Office of Komarom, but only up to low-water levels. This did not prove effective enough. Spur dikes to reinforce the shore were also built at the lower end of Nyarassziget, but were too short to narrow the channel. The River Engineering Institute of Győr raised the dams at Tat (1,727 kilometers) in 1949 and at Nyarassziget (1,725 kilometers) in 1950 to the average water level. But this section of the channel needs improvement also in connection with low-water regulation.

Further difficulties to navigations are presented by the shoals at Danamoc (1,745.5 kilometers), where the desired navigation depth was insured by the construction of one or two spur dikes on the left side, and at Prepostsziget (1,757-1,755 kilometers), where both flood and average-water volumes are spread out too much and the required shipping depth cannot be maintained. The channel could be improved in this section by two or three spur dikes at the island and by closing the forks at the same time.

It is clear from the above that low-water regulation must be undertaken to supplement existing improvements. Improvement of the Garamkovesd shoals, the lowest of the series, was begun in 1943.

There is a concentration of factors menacing shipping at the Garamkovesd shoals (1,714 kilometers). The upper and lower shelves are separated by a high ridge which extends over the middle of the channel. The water depth above this ridge is very slight, but in passing over it the velocity of flow is accelerated. The shipping channel here runs almost at right angles to the channel's main course, which makes steering difficult. During some years, the extent of deterioration of these shoals has equaled that of the shoals of the upper Danube. Here, too, it has sometimes been necessary to improve the shipping channel by dredging.

In 1943 this area was improved by introduction of the new method used in low-water regulation along the upper Danube. The result has been that even today these flats are 50 centimeters deeper than other shoals near them. They were improved by the former River Engineering Office of Komarom which constructed three spur dikes on the right side and dredged an 80-meter-wide channel within the shipping channel. The function of the spurs was to direct the flow of water into the Deda fork on the right of Helembasziget into the deepened area so that its scour would further deepen the channel bed and achieve the required depth.

Although the Garamkovesd shoals have been in good condition since 1943, not all problems presented by them have been solved as yet. The deposit of sediment carried by the Garam River may cause further shipping difficulties. For this reason, over-all plans for the improvement of these shoals must include elimination of accumulation by the Garam and the improvement of the mouth of that river.

### 3. Section Between the Mouth of the Ipoly River and the Pifurcation at Szenteadresziget (1,708-1,692 kilometers)

This section presents particular difficulties to shipping. A channel depth of 3 meters is maintained at low-water levels. However, rocks in the river bed between Zebegeny and Nagymaros (1,703-1,695 kilometers) are a hindrance to navigation.

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Improvement constructions in this section are concerned with flood prevention and channel regulation.

### 1. Flood Prevention Works

As far as flood prevention is concerned, the same conditions exist in the section below Paks as those described for the section above it. The position of the embankments and the resulting great differences in the width of the overflow areas, are alarming. Between Paks and the mouth of the Sio River, the distances between the two embankments are in some places less than one kilometer. The width of the overflow area is particularly small above Pokto (1,520 kilometers) and at Garjen (1,516 kilometers); at both places the overflow area is less than one kilometer wide. To aggravate the situation, a considerable part of the normal channel is narrowed by sand bars. No extended overflow area exists on the left side of the bars and on the right side it is covered by trees. At the edge of Fajsz (1,508 kilometers), the unfortunate angle of the left embankment narrows the overflow area. At the Bogvisszlo cut (1,504-1,498 kilometers), the situation is equally dangerous, because the narrow overflow area is on high ground, mostly covered with woods. All the stretches enumerated here are potentially dangerous, because ice barriers form easily along them, resulting in floods and in breaks in the shore dikes. Destructive floods have often occurred in these areas in the past.

From the outlet of the Sio River down past Baja as far as Bata, flood dikes were placed along the banks of the original river bends, even though these had been cut through. The average width of the overflow area here is 4.5 kilometers and it exceeds 7 kilometers in some places. Nevertheless sand bars form where the channel forks at the entrances into the short cuts, making navigation difficult and preventing the even passage of ice. This situation is particularly obvious at the place where the overflow area is widest, at the mouth of the Sio River, where a succession of large sand bars is located. Ice floes are easily arrested here and ice blocks are likely to form upriver (Hatfo shoals, 1,498 kilometers).

The overflow area narrows again along the stretch between Bata and Dunaszekcső (1,465-1,460 kilometers). Its width at Dunaszekcső is 425 meters, scarcely greater than at Budapest. The main part of Dunaszekcső lies on a hill on the right bank, but part of the town lying on the left side would suffer greatly if the dikes were breached. There is no possibility for improving the position of the dikes here and the dangerous situation can be alleviated only by raising and strengthening them.

Although flood dikes provide adequate protection against normal floods, they are not adequate protection against floods caused by spring thaws. The alignment of dikes along places where the width of the overflow area is less than three times the width of the normal channel must be made the subject of special study. Protective dikes below Budapest in general have a height of more than one meter above the highest levels recorded for floods not due to thaws. But since icy floods are much more dangerous and involve a much greater volume of water, the protective dikes should be raised to a height of at least one meter above the highest recorded thaw-flood level.

### 2. Channel Regulation Works

The most important step toward the prevention of ice barricades was taken when the Hungarian government cut through the great bends between Paks and the mouth of the Drava River. But development of the short cuts did not end this danger and supplementary improvements should have been made along the section.

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## IV. SUMMARY

A. Chief Problems of the Various Sections

The following are the main problems presented by the various sections in brief summary: rise of the river bed along the upper Danube; excessively wide normal channel between Gonyu and Budapest; ice barriers and icy floods between Budapest and Eszja; erosion of the banks; and formation of ice barricades and meanders between Paks and the southern frontier.

B. Tasks

Along the upper Danube, both the overflow area and the normal channel must be improved. The overflow channel must be narrowed by guiding dikes and by side forks; and the average channel must be further narrowed by regulation of the low-water channel.

Between Gonyu and Budapest, the average channel must be narrowed by use of the system of changing profiles.

Below Budapest, average-channel regulation must be supplemented by low-water channel regulation. In some places the longitudinal dikes should be rearranged and the embankments raised. Where the overflow area is narrow, it should be cleared of all trees and bushes.

Below Paks, the banks should be reinforced and the channel made more even so that ice flows can be easily discharged.

C. Miscellaneous Data on Regulation

The required water depth below the minimum navigation water level is 2.5 meters above Gonyu, 3 meters between Gonyu and Budapest, and 3.5 meters below Budapest.

The required width of the regulated channel is 300 meters above Esz, 380 meters between Esz and Venek, and 400 meters below Venek to the border.

The height of the crest of the old longitudinal dikes above the zero water level is 3 meters above Esz, 2.75 meters between Esz and Dunaradvany, 3 meters along the Budafok fork, and 2.5 meters from the lower end of Csapel Island southward.

The height of the crest of the new longitudinal dikes along the Vac branch is 3 meters above the basic water level of the year 1930 at the apex of bends and 0.5 meter above the same level at the inflection points.

The distance between the spur dikes in a series generally equals half the channel width to be obtained by regulation.

The height of the bases of the old spur dikes along the upper Danube is 75 centimeters below the minimum navigation water level.

The height of the bases of the new spur dikes along the upper Danube is 75 centimeters below the minimum navigation water level at the inflection point of bends, but increases gradually toward the apex of the bend, where it rises one meter above the minimum navigation water level.

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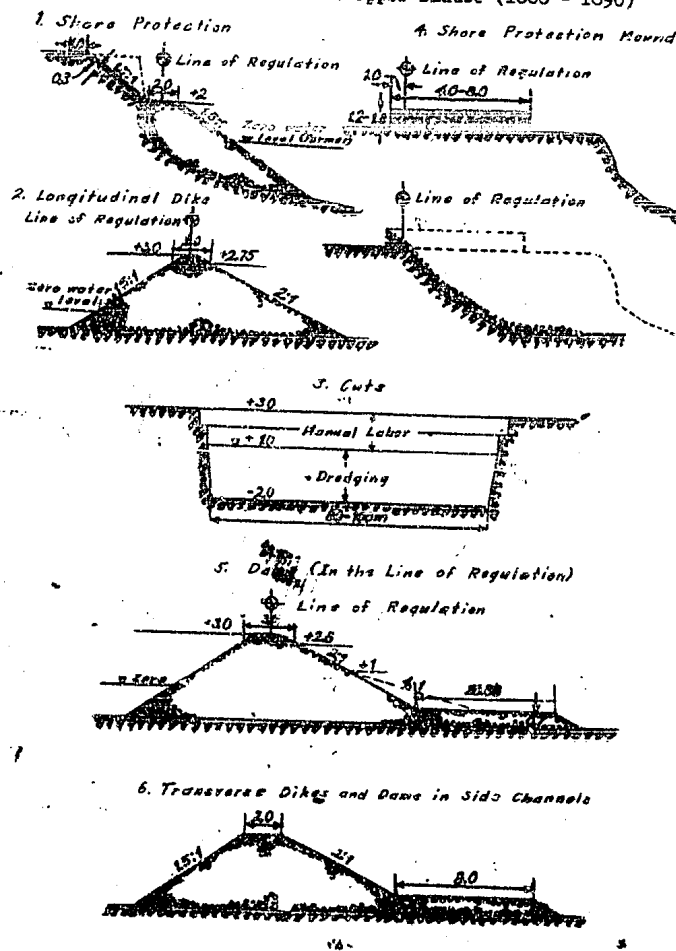
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The height of the bases of the spurs along the Vac branch is equal to the minimum navigation level at the inflection point (50 centimeters above the 1930 basic level), and 1.5 meters above the minimum navigation level (2 meters above the 1930 basic level) at the apex.

Since the channel of a river undergoes constant changes (rises or falls, erodes along its concave side and deposits along its convex side), the measurements indicated above are useful only as guides. At present, the height of construction established, not according to the zero gauge levels, but according to the minimum water level desired for navigation purposes. The height of the new low-water level will be communicated to the Danube regulation authorities by decree after negotiations have been completed with the International Danube Commission.

[Appended figures follow.]

Figures 1-6. Constructions Used in Regulation of the Average Channel of the Upper Danube (1886 - 1896)



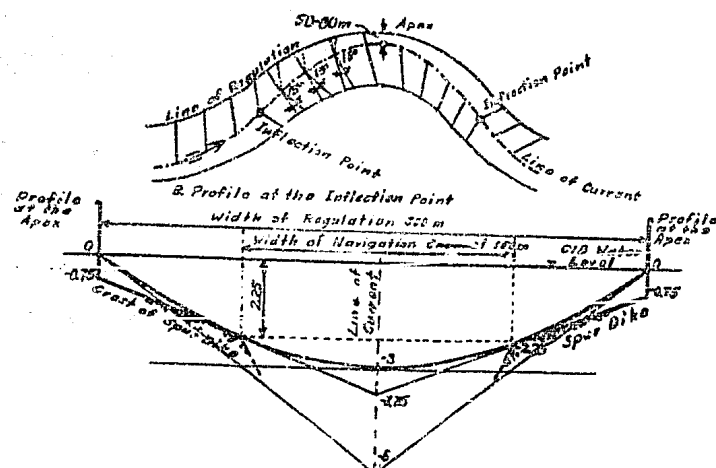
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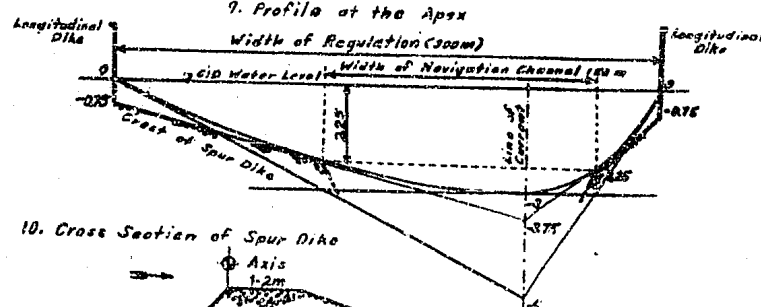
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Figures 7-10. Original Construction (Prior to 1936)  
Used in Low-Water Regulation of the Upper Danube

7. Distribution of Spur Dikes



8. Profile at the Inflection Point



9. Profile at the Apex



10. Cross Section of Spur Dike



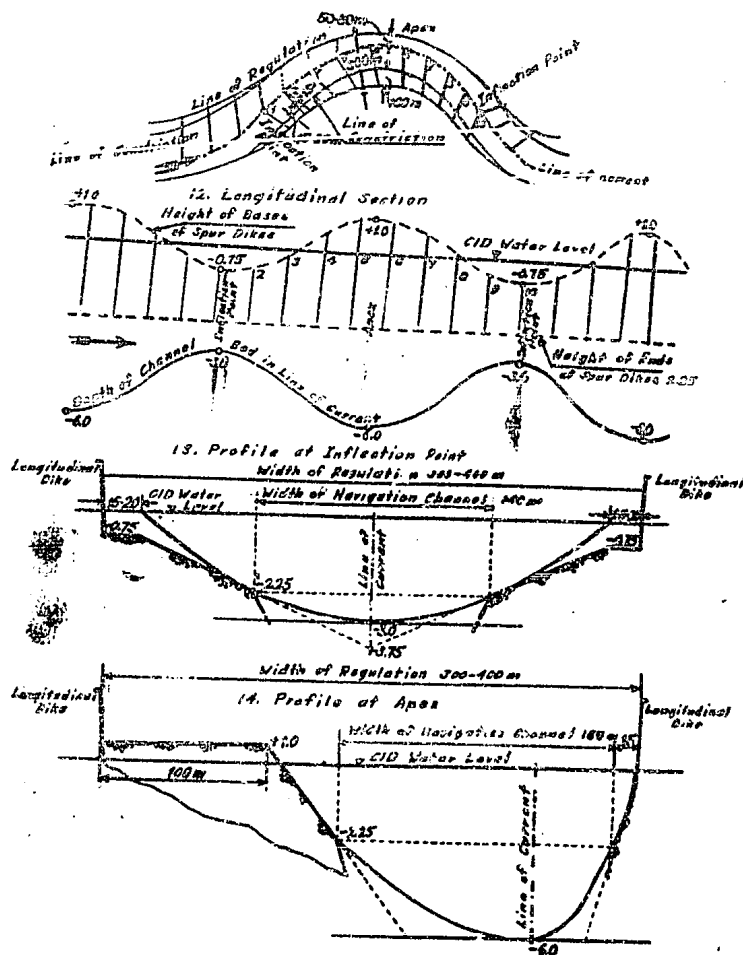
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Figures 11-14. New Constructions (Since 1936)  
Used in Low-Water Regulation of the Upper Danube

## 11. Distribution of Spur Dikes



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